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# Concurrence of rule- and similarity-based mechanisms in artificial grammar learning

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ABSTRACT

A current theoretical debate regards whether rule-based or similarity-based learning prevails during artificial grammar learning (AGL). Although the majority of findings are consistent with a similarity-based account of AGL it has been argued that these results were obtained only after limited exposure to study exemplars, and performance on subsequent grammaticality judgment tests has often been barely above chance level. In three experiments the conditions were investigated under which rule- and similarity-based learning could be applied. Participants were exposed to exemplars of an artificial grammar under different (implicit and explicit) learning instructions. The analysis of receiver operating characteristics (ROC) during a final grammaticality judgment test revealed that explicit but not implicit learning led to rule knowledge. It also demonstrated that this knowledge base is built up gradually while similarity knowledge governed the initial state of learning. Together these results indicate that rule- and similarity-based mechanisms concur during AGL. Moreover, it could be speculated that two different rule processes might operate in parallel; bottom-up learning via gradual rule extraction and top-down learning via rule testing. Crucially, the latter is facilitated by performance feedback that encourages explicit hypothesis testing.


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## 1. Introduction

The question, what do people learn when they are exposed to highly structured complex stimuli, initially posed over 40 years ago (Reber, 1967), is still intensely debated. Of the major concern for cognitive psychology is the question whether people are able to learn abstract rules or whether they base their judgments about novel instances on the similarity of these instance to some previously-encountered cases. The rule-based vs. similarity-based debate has previously been considered in many contexts: in theories of reasoning (Ross, 1989; Ross & Kennedy, 1990; Sun, 1995), in instance-based models of implicit learning (Berry & Broadbent, 1984; Redington & Chater, 2002; Vokey & Brooks, 1992), or in the domain of category learning (Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Ashby & O'Brien, 2005; Erickson & Kruschke, 1998; Maddox, Ashby, & Bohil, 2003). For example, within the domain of category learning there is considerable empirical evidence that rule-based and similarity-based mechanisms both contribute to learning (e.g., Ashby & Maddox, 2005). One paradigm that is particularly well suited to investigate this question is artificial grammar learning (AGL). This is because AGL paradigms afford the differential assessment of learnable structures (Fitch & Hauser, 2004; Lai & Poletiek, 2011; Poletiek, 2011; Vries, de Vries, Monaghan, Knecht, & Zwitserlood, 2008), and the properties which facilitate the learning of those structures (Endress, Scholl, & Mehler, 2005; Gómez & Gerken, 2000; Marcus, Vijayan, Rao, & Vishton, 1999). A typical AGL experiment contains two phases. In the exposure or training phase participants are presented with some letter strings. Unbeknown to participants, these letter strings, also called grammatical items, are generated by a finite state grammar. Subsequent to the exposure phase participants are presented with novel items comprising either grammatical or non-grammatical sequences. Their task is to identify those letter strings that violate the finite state grammar. A series of studies has shown that participants perform this task above chance (e.g., Dienes, Broadbent, & Berry, 1991; Kinder & Assmann, 2000; Lotz & Kinder, 2006; Mathews et al., 1989; Pothos & Bailey, 2000; Reber, 1967, 1976, 1989). Two major competing theories have been proposed to account for this result (see Pothos, 2005, 2007 for reviews). Both are highly plausible and supported by substantive empirical evidence. One view proposes that participants perform this task by judging the similarity of the novel stimuli in reference to the stimuli, or at least fragments of these stimuli, memorised in the exposure phase (Brooks & Vokey, 1991; Kinder & Assmann, 2000; Perruchet & Rey, 2005; Vokey & Brooks, 1994).

An alternative view suggests that rules underlying the construction of these stimuli are learned (Mathews et al., 1989; Reber, 1989). Rule-based accounts are highly attractive because, for example, one easily reckons why the number 1356 is even or whether a geometric shape represents a triangle. Further phenomenological evidence for the existence of rules in cognition has been previously demonstrated (Smith, Langston, & Nisbett, 1992). Applied to artificial grammar learning, rules can be understood as a computational construct of mental representations capturing abstract statistical regularities of several grammatical stimuli (Opitz, 2010; Sun, 1995) or as mental operations allowing the characterisation of a stimulus according to a minimal number of features (Pothos, 2007). Irrespective of the exact understanding of rules, both views share a number of assumptions about rules (see Hahn & Chater, 1998 for a detailed discussion of these assumptions). Among them, rules are considered to be *compositional* so that complex rules can be constructed from simple rules. For example, two rules 'Valid strings of the artificial grammar start with T' and 'Valid strings end with R' can be combined into the compositional rule 'Valid strings start with T and end with R'. Furthermore, rules imply abstract representations to allow for generalisation to a sufficiently large number of instances. Rules also represent an exact and rigorous description of the relevant abstract knowledge. The downside of this property is the inflexibility and limited scope of rule judgments: for the rule to apply, the preconditions of the rule must typically be matched in an all-or-none fashion (Hahn & Chater, 1998). Critically, if not all preconditions are known the missing ones must be assumed to match. For instance, to classify an animal that has four legs and is fury as a dog one has to assume that, among other features, it barks, as well. If that assumption is not made, than the rule does not apply to that particular item. Note that, although not knowing all preconditions causes some uncertainty in the applicability of a rule, the actual application of this rule implies that all preconditions were (assumed to be) met. There is no intermediate state that allows for some flexibility in the application of rules.